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Validation of reverse circulation drilling rig for reconciliation purposes

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Representative samples of ore containing precious metals is a difficult task. The lower the grade and the higher the nugget and/or cluster effect, the more complex and difficult extracting samples that are both accurate and precise. Reconciliation practices can be used as an effective tool to evaluate sampling accuracy throughout grade control processes. However, a proper reconciliation system must be based on reliable data and, therefore, optimisation of sampling techniques is a must for development of a reliable reconciliation system. This paper is a result of an extensive reconciliation study carried out at a copper and gold mine in Brazil, where a significant reconciliation problem took place while using manual sampling for grade control and short-term modeling. After analysing several sampling equipment/sample selection techniques, the authors suggested the use of a reverse circulation drilling rig with an automatic sampling system for grade control sampling. The samples generated by this automatic system were compared with the manual samples collected from the piles generated by the previous percussion rotary air blast drilling rig. Also, three pairs of twin holes were drilled in order to validate the new reverse circulation approach. Results allowed estimation of the bias related to the increment weighting error (IWE) generated by manual sampling, and show that the reverse circulation rig eliminates significant sampling biases, thus improving the general sample representativeness by increasing both sample accuracy and precision.

Introduction

Sampling is an essential operation performed in many stages of a mining project: before its implementation, during mineral exploration for resources and reserves evaluation, and after its implementation, during mining and minerals processing for short-term planning, process control and reconciliation. Sampling is defined as a sequence of operations that aims to take a significant part, or sample, of a given lot[1]. Reconciliation, in turn, consists of comparing the tonnages and grades estimated by the geological models with the tonnages and grades obtained in the processing plant.

The main objective of this work was to optimise sampling procedures of a copper and gold mine in Brazil, where sampling for reconciliation purposes traditionally has been performed using a blast-hole drilling rig, model HCR1500 by Furukawa. After drilling, samples were manually collected from the coarse material pile using shovels.

According to Pitard[2], the main problems related to blast-hole sampling are: upward and downward contamination during drilling, upward losses during drilling, refluxing during drilling, sub-drill material disposal at the top of the pile, poor recovery of the former sub-drill, pile segregation, pile shape irregularity, loss of fines, deterministic and operator-dependent sampling, sampling interfering with mining productivity, and a too small sample mass (not enough for representativeness), resulting in massive misclassification of ore and waste. The same author lists the many advantages of separate drilling campaigns using reverse circulation drilling rigs, which includes: absence of a sub-drill, possibility to drill several benches at once, possibility to drill at an appropriate angle (perpendicular to the mineralisation structure), limited contamination and losses, no interferences with mining productivity, possibility of drilling many months ahead of mining time, smaller representative sample masses (since the chips are usually smaller than the ones generated by blast-hole drilling rigs), better mining logistics, easier automation of sampling, more accurate and precise grade control.

In 2013[3], the authors presented the results of a sampling campaign in the same mine, which demonstrated the tendency of the Furukawa to overestimate both gold and copper grades, especially due to poor recovery (only 80%) coupled with segregation between fines and coarse material. Therefore, a reverse circulation (RC) drilling rig with automatic sampling system (recovery of up to 99%) was recommended, in order to minimise the errors generated by manual sampling, such as the increment delimitation error, the increment extraction error, the increment weighting error and the grouping and segregation error (IDE, IEE, IWE, GSE).

This paper presents the results of sampling optimization for reconciliation purposes, based on the validation of the RC ROC L8 drilling rig with an automatic sampling system by Atlas Copco. The advantages of working with this type of rig offset the cost of acquisition, especially when dealing with very heterogeneous and geologically complex deposits.

Methodology

The mine selected for this study has a very complex geology. Gold and copper do not correlate with one another and are not preferably associated with any of the geological structures, requiring a versatile and appropriate sampling system to determine the limits between ore and waste. In addition, low grades and variable rock type occurrences make sampling even more difficult.

Earlier sampling procedure

The previous sampling approach was carried out using a Furukawa HCR1500, a percussion rotary air blast drilling rig with a 3.5" drill bit. This rig has two outputs originating from the cyclone underflow (front discharge: coarse and medium fragments) and overflow (rear discharge: fine fragments). The rig also has 5 filters, through which all fine material passes before being discharged, constituting one of the likely sources of contamination, as part of the material is retained in the filters and is first eliminated later together with material from the next hole.

The previous method consisted in manual collection of 12 increments from the medium and coarse pile, using a shovel. The fines were discarded because (according to the sampling team): "the fines 'salt' the sample, which does not reconcile with the plant"[*sic*].

The previous work[3] proved that this drilling rig is not able to recover all the material from the hole, especially the coarse and consequently lower grade material. Thus, the fragments sent to the surface piles (finer fragments) are richer than the original lot (all fragments composing the drill hole: fines, medium and coarse). It was observed that in a 10 m drill hole, approximately 2 m of material could remain in the hole. Over time, incorrect sampling of coarser material has been compensating the error due to the Furukawa's low recovery, generating excellent, but illusory, reconciliations[4].

New sampling procedure

The new equipment acquired for short and medium-term sampling is an RC Atlas Copco ROC L8, equipped with a 5.5" drill bit and which is capable of recovering up to 99% of the drilled material. The RC drilling rod has a lining inside which the fragments are lifted, minimizing the material loss inside fractures and avoiding contamination with fragments from the wall of the drill hole. The fragments are then sent directly to the automatic sampling system, where they are split by a riffle splitter. Figure 1 shows the drilling rig with the automatic sampling system.

Compressed air moves between the drill pipes, recovering the material and sending it to a ceramic baffle to reduce the speed of the particles. Upon reaching the desired depth, the drilling is interrupted and the material is discharged through the automatic quartering system, consisting of three sets of riffle splitters which generate the sample and the waste (Figure 2).

In order to validate the new sampling system and compare it to the old, three twin holes were executed. The samples were taken every 5 m, resulting in a total of 10 samples altogether: two from hole #1, four from hole #2 and four from hole #3. The remaining material was also collected: for the Furukawa, this was composed of the fines and the remaining part of the coarse pile; for the RC ROC L8, the remaining material was composed of the rejects of the riffle splitters and the material deposited on the top surrounding the hole.

Figure 1. RC ROC L8 drilling rig with automatic sampling system.

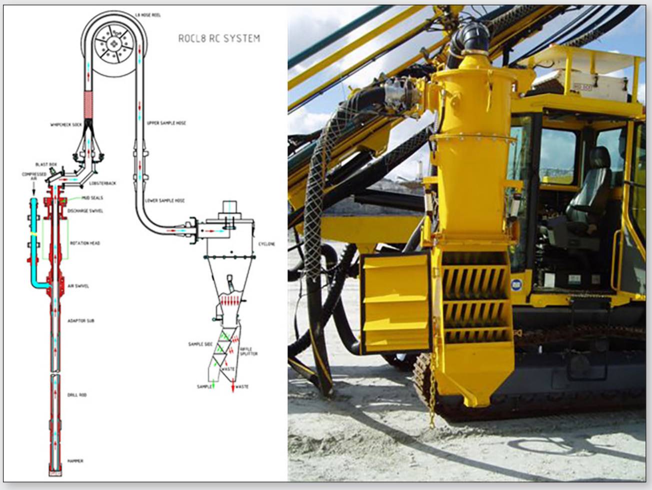

Figure 2. Drill hole material pathway until reaching the automatic sampling system, consisting of three sets of riffle splitters.

The twin holes sampling procedure is described as follows:

- Drilling (Furukawa), stopping every 5 meters.
- Collection of 12 increments sample using a shovel.
- Collection of the remaining material.
- Drilling (RC ROC L8), stopping every 5 meters.
- Collection of the sample generated by the automatic sampling system.
- Collection of the remaining material.

Results

The data processing is designed to perform the following analyses:

- Accuracy of the Furukawa drilling rig for sampling purposes.
- Quality of samples generated by each sampling method.

Accuracy of the Furukawa drilling rig

Comparing the results of this study with those of the previous study[3] showed that the Furukawa tends to overestimate the actual gold and copper grades, with an average relative error of +57.6% and

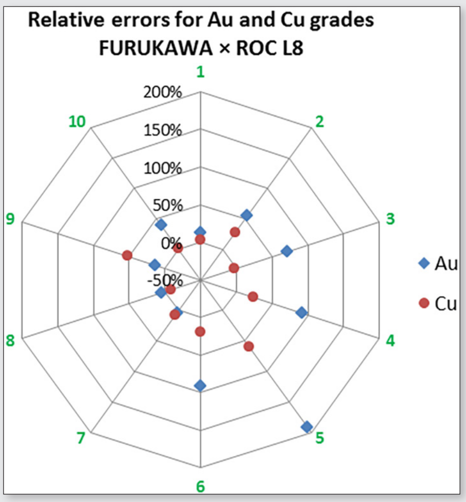

Figure 3. Furukawa relative errors for copper and gold grades compared to RC ROC L8 twin holes.

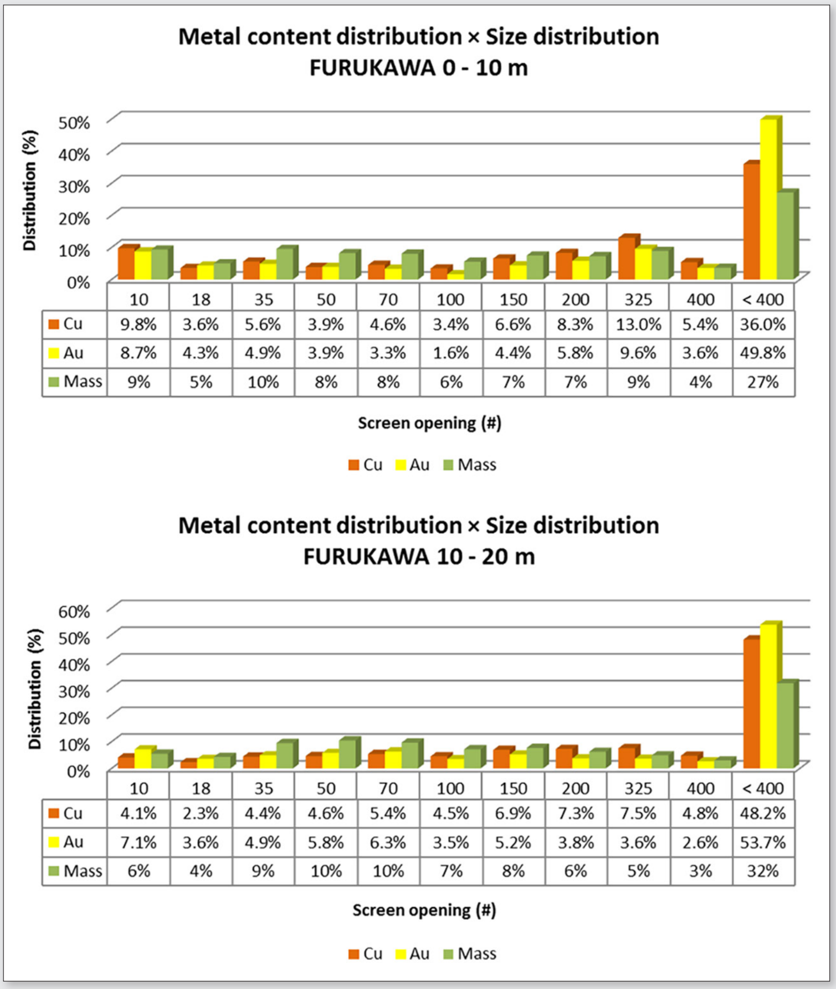

Figure 4. Distribution of gold and copper content, and mass retained, for 11 size fractions. Calculations are based on size distribution and chemical analysis for all material recovered by the Furukawa rig from hole #3 (0 to 10 m and 10 to 20 m).

+18.3% respectively. These errors were calculated relatively to the corresponding grades of the material from the twin holes recovered by the RC ROC L8. Figure 3 (related to Table 3) shows the gold and copper relative errors for all 10 individual samples.

This figure shows that the error dispersion related to gold is much higher than the one related to copper, and indeed that all samples were overestimated for gold while 80% of the samples were overestimated for copper.

Quality of samples – Furukawa

The quality of manual samples taken from the material recovered by the Furukawa can be characterised in two ways:

- Comparing the grades of manual samples with the grades of all the material recovered by the Furukawa.
- Comparing the grades of manual samples with the grades of all the material recovered by the RC ROC L8 (twin holes).

Figure 4 shows that both copper and gold are concentrated in the finest size fraction, since most of the contained gold (49.8% Au and 53.7% Au) and the contained copper (36.0% Cu and 48.2% Cu) is in the -400# fraction. Thus, samples taken from the coarse fragments pile will underestimate the grades, due to the increment weighting error (IWE).

Table 1 shows the errors associated with manual sampling relative to the grades calculated for all the material recovered by the Furukawa, showing a clear pattern of underestimation.

Table 2 shows the errors associated with manual sampling relative to the grades calculated for all the material recovered by the RC ROC L8, showing a pattern of overestimation.

Interestingly, unlike to the results shown in Table 1, in this case manual sampling leads to an overestimation of the hole grades. This can be explained by the fact that the Furukawa doesn't recover the coarser/poorer fragments and thus overestimates the gold grades in 57.6% and the copper grades in 18.3% (see relative error means in Table 3). Even though the samples have an underestimation trend (–12.6% for gold and –7.1% for copper: see relative error means in Table 1), this is not enough to compensate the error induced by the drilling rig. It's important to note that, if increments were collected from the fines pile as well, the overestimation trend of manual samples would be even greater.

Since one error compensates another in the earlier approach, it was often possible to obtain what *appeared* as excellent reconciliations – even with very poor and biased samples. The fact that reconciliation results were deceptively satisfactory did not allow, for years, proper recognition of the errors involved and the optimization of sampling procedures in order to ensure the

Table 1. Absolute and relative errors for Cu and Au grades comparing Furukawa samples (Sample) with all the material recovered by Furukawa (Total)

g/t Au (FURUKAWA)					%Cu (FURUKAWA)				
Hole/Depth	Total	Sample	ABS Error	REL Error	Hole/Depth	Total	Sample	ABS Error	REL Error
H1/0-5 m	0.345	0.294	-0.051	-14.7%	H1/0-5 m	0.435	0.408	-0.027	-6.2%
H1/5-10 m	0.110	0.081	-0.029	-26.5%	H1/5-10 m	0.179	0.141	-0.038	-21.1%
H2/0-5 m	0.907	0.825	-0.082	-9.0%	H2/0-5 m	0.522	0.503	-0.019	-3.6%
H2/5-10 m	0.185	0.131	-0.054	-29.0%	H2/5-10 m	0.205	0.188	-0.017	-8.2%
H2/10-15 m	0.081	0.060	-0.021	-25.8%	H2/10-15 m	0.138	0.128	-0.010	-7.5%
H2/15-20 m	0.048	0.037	-0.011	-22.9%	H2/15-20 m	0.115	0.111	-0.004	-3.8%
H3/0-5 m	0.294	0.282	-0.012	-3.9%	H3/0-5 m	0.483	0.506	0.023	4.8%
H3/5-10 m	0.100	0.111	0.011	10.8%	H3/5-10 m	0.172	0.193	0.021	12.4%
H3/10-15 m	0.045	0.047	0.002	4.6%	H3/10-15 m	0.155	0.102	-0.053	-34.3%
H3/15-20 m	0.043	0.038	-0.005	-11.7%	H3/15-20 m	0.105	0.102	-0.003	-2.8%

Mean	-0.022	-12.6%	Mean	-0.011	-7.1%
Variance	0.00085		Variance	0.00061	
Standard deviation	0.029		Standard deviation	0.025	
Representativeness ($r^2 = m^2 + s^2$)	0.0013		Representativeness ($r^2 = m^2 + s^2$)	0.00074	

Table 2. Absolute and relative errors for Cu and Au grades comparing Furukawa samples (Sample FK) with all the material recovered by RC ROC L8 (Total L8)

g/t Au (ROC L8 × FURUKAWA)					%Cu (ROC L8 × FURUKAWA)				
Hole/Depth	Total L8	Sample FK	ABS Error	REL Error	Hole/Depth	Total L8	Sample FK	ABS Error	REL Error
H1/0-5 m	0.306	0.294	-0.012	-4.0%	H1/0-5 m	0.425	0.408	-0.017	-4.0%
H1/5-10 m	0.071	0.081	0.010	14.3%	H1/5-10 m	0.140	0.141	0.001	0.7%
H2/0-5 m	0.532	0.825	0.293	55.2%	H2/0-5 m	0.538	0.503	-0.035	-6.4%
H2/5-10 m	0.096	0.131	0.035	36.0%	H2/5-10 m	0.166	0.188	0.022	13.3%
H2/10-15 m	0.028	0.060	0.032	116.8%	H2/10-15 m	0.086	0.128	0.042	48.2%
H2/15-20 m	0.025	0.037	0.012	47.7%	H2/15-20 m	0.096	0.111	0.015	15.1%
H3/0-5 m	0.282	0.282	0.000	-0.1%	H3/0-5 m	0.446	0.506	0.060	13.4%
H3/5-10 m	0.095	0.111	0.016	16.9%	H3/5-10 m	0.187	0.193	0.006	3.2%
H3/10-15 m	0.040	0.047	0.007	18.6%	H3/10-15 m	0.102	0.102	0.000	-0.3%
H3/15-20 m	0.031	0.038	0.007	23.1%	H3/15-20 m	0.104	0.102	-0.002	-2.1%

Mean	0.040	32.5%	Média	0.009	8.1%
Variance	0.0081		Variância	0.00075	
Standard deviation	0.090		Desvio Padrão	0.027	
Representativeness ($r^2 = m^2 + s^2$)	0.010		Representatividade ($r^2 = me^2 + se^2$)	0.00083	

representativeness of samples and hence the reliability of reconciliation results[4].

Quality of samples – RC ROC L8

Table 4 shows the errors estimates associated with the automated sampling system of RC ROC L8 relative to the grades calculated for all the material recovered by the same drilling rig. An important aspect is the absence of a systematic error, or bias, i.e., the samples do not have a tendency to underestimate or overestimate the grades (50% of the samples underestimate gold grades and 60% of the samples underestimate copper grades).

Figure 5 shows a comparison between the particle size distributions of the RC ROC L8 sample and the particle size distribution of all the material recovered by the RC ROC L8. This figure also shows the same comparison for the Furukawa, which presents very different distributions, proving the observed bias.

This display proves beyond any doubt that the RC ROC L8 distributions are fully compatible and that there's no selection of a particular size fraction at the expense of others. Knowing that if one wants to represent the grades, the imperative is to represent the complete particle size distribution, it can be stated that the RC ROC L8 automatic sampling system generates samples that are fully representative of the original lot.

Conclusions

Based on the presented results, the following conclusions can be made:

- The Furukawa overestimates both copper and gold grades, mainly because of the upward losses during drilling.

Table 3. Absolute and relative errors for Cu and Au grades comparing all material recovered by Furukawa (Total FK) with all the material recovered by RC ROC L8 (Total L8)

g/t Au (ROC L8 × FURUKAWA)				
Hole/Depth	Total L8	Total FK	ABS Error	REL Error
H1/0-5 m	0.306	0.345	0.038	12.5%
H1/5-10 m	0.071	0.110	0.039	55.6%
H2/0-5 m	0.532	0.907	0.375	70.5%
H2/5-10 m	0.096	0.185	0.088	91.7%
H2/10-15 m	0.028	0.081	0.053	192.2%
H2/15-20 m	0.025	0.048	0.023	91.7%
H3/0-5 m	0.282	0.294	0.011	4.0%
H3/5-10 m	0.095	0.100	0.005	5.5%
H3/10-15 m	0.040	0.045	0.005	13.4%
H3/15-20 m	0.031	0.043	0.012	39.4%

Mean	0.065	57.6%
Variance	0.013	
Standard deviation	0.112	
Representativeness ($r^2 = m^2 + s^2$)	0.017	

%Cu (ROC L8 × FURUKAWA)				
Hole/Depth	Total L8	Total FK	ABS Error	REL Error
H1/0-5 m	0.425	0.435	0.010	2.3%
H1/5-10 m	0.140	0.179	0.039	27.7%
H2/0-5 m	0.538	0.522	-0.016	-2.9%
H2/5-10 m	0.166	0.205	0.039	23.4%
H2/10-15 m	0.086	0.138	0.052	60.2%
H2/15-20 m	0.096	0.115	0.019	19.7%
H3/0-5 m	0.446	0.483	0.037	8.2%
H3/5-10 m	0.187	0.172	-0.015	-8.2%
H3/10-15 m	0.102	0.155	0.053	51.7%
H3/15-20 m	0.104	0.105	0.001	0.8%

Mean	0.022	18.3%
Variance	0.00067	
Standard deviation	0.026	
Representativeness ($r^2 = m^2 + s^2$)	0.0011	

Table 4. Absolute and relative errors for Cu and Au grades comparing RC ROC L8 samples (Sample) with all the material recovered by the RC ROC L8 (Total)

g/t Au (ROC L8)				
Hole/Depth	Total	Sample	ABS Error	REL Error
H1/0-5 m	0.306	0.282	-0.024	-8.0%
H1/5-10 m	0.071	0.069	-0.002	-2.6%
H2/0-5 m	0.532	0.578	0.046	8.7%
H2/5-10 m	0.096	0.121	0.025	25.6%
H2/10-15 m	0.028	0.025	-0.003	-9.7%
H2/15-20 m	0.025	0.037	0.012	47.7%
H3/0-5 m	0.282	0.277	-0.005	-1.8%
H3/5-10 m	0.095	0.082	-0.013	-13.6%
H3/10-15 m	0.040	0.044	0.004	11.1%
H3/15-20 m	0.031	0.036	0.005	16.6%

Mean	0.0046	7.4%
Variance	0.00039	
Standard deviation	0.020	
Representativeness ($r^2 = m^2 + s^2$)	0.00041	

%Cu (ROC L8)				
Hole/Depth	Total	Sample	ABS Error	REL Error
H1/0-5 m	0.425	0.320	-0.105	-24.7%
H1/5-10 m	0.140	0.140	0.000	0.0%
H2/0-5 m	0.538	0.551	0.013	2.5%
H2/5-10 m	0.166	0.166	0.000	0.0%
H2/10-15 m	0.086	0.081	-0.005	-6.2%
H2/15-20 m	0.096	0.093	-0.003	-3.5%
H3/0-5 m	0.446	0.422	-0.024	-5.4%
H3/5-10 m	0.187	0.168	-0.019	-10.1%
H3/10-15 m	0.102	0.097	-0.005	-5.1%
H3/15-20 m	0.104	0.105	0.001	0.8%

Mean	-0.015	-5.2%
Variance	0.0011	
Standard deviation	0.033	
Representativeness ($r^2 = m^2 + s^2$)	0.0013	

- The earlier manual sampling procedure tends to select only the coarser particles, thereby underestimating gold and copper grades – but this trend has been masked by an overestimation tendency by the drilling rig.
- The fines discard from the manual sampling procedure is incorrect. However, its positive results were due to a particular compensation of errors that led to a completely illusory reconciliation.
- Comparing with the grades of all the material recovered by the RC ROC L8, the samples generated by its automatic sampling system do not result in any systematic errors. This new system is unbiased.
- The samples generated by the RC ROC L8 are representative with respect to both total particle size distribution and to the gold and copper grades for individual particle size fractions.
- Knowing that the reliability of the reconciliation results depends on the quality of the input data, the authors conclude that the RC ROC L8 sampling system has been validated for reconciliation purposes.

The economic impact generated by incorrect sampling procedures should never be underestimated. In this study, the intrinsic errors in the process were being masked by compensations, and may have eventually led to erroneous interpretation of the reconciliation results, from which significant ore losses and ore dilution take place. These problems are amplified when production reaches poorer or more heterogeneous regions of the deposit.

Knowing that errors are amplified for lower grades, and considering the high geological complexity of the deposit, implementation of the new automatic sampling system is the only logical solution for effective control of mining operations. The new RC drilling rig

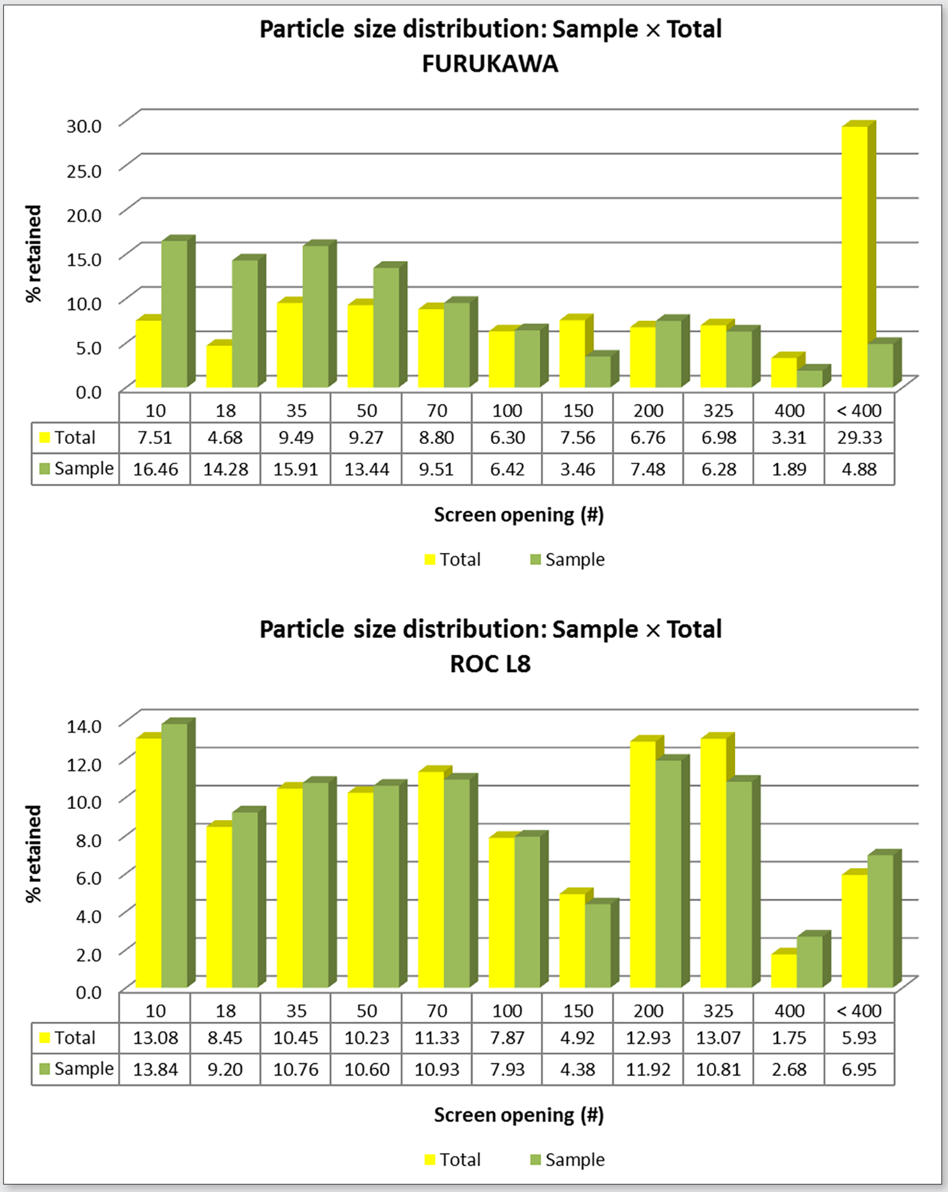

Figure 5. Particle size distributions comparing the samples with the total recovered material for Furukawa and RC ROC L8.

showed very encouraging results with respect to sample representativeness and significantly increased reconciliation reliability.

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